ECL 1-14

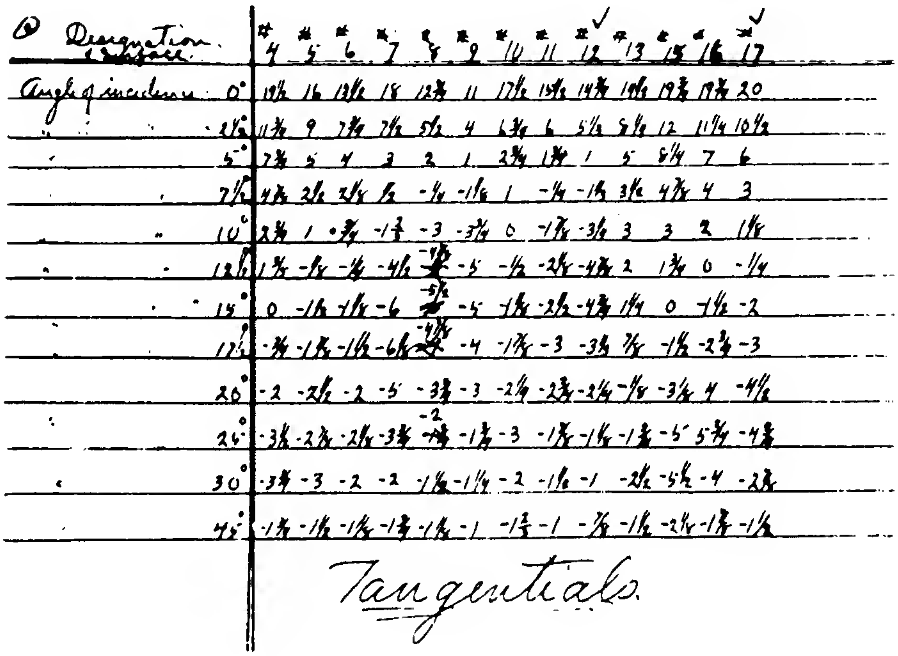
EDUCATIONAL DEVELOPMENT PROGRAM

UNIVERSITY OF CALIFORNIA . DEPARTMENT OF ENGINEERING . LOS ANGELES, CALIFORNIA

THE WRIGHT BROTHERS' AIRPLANE

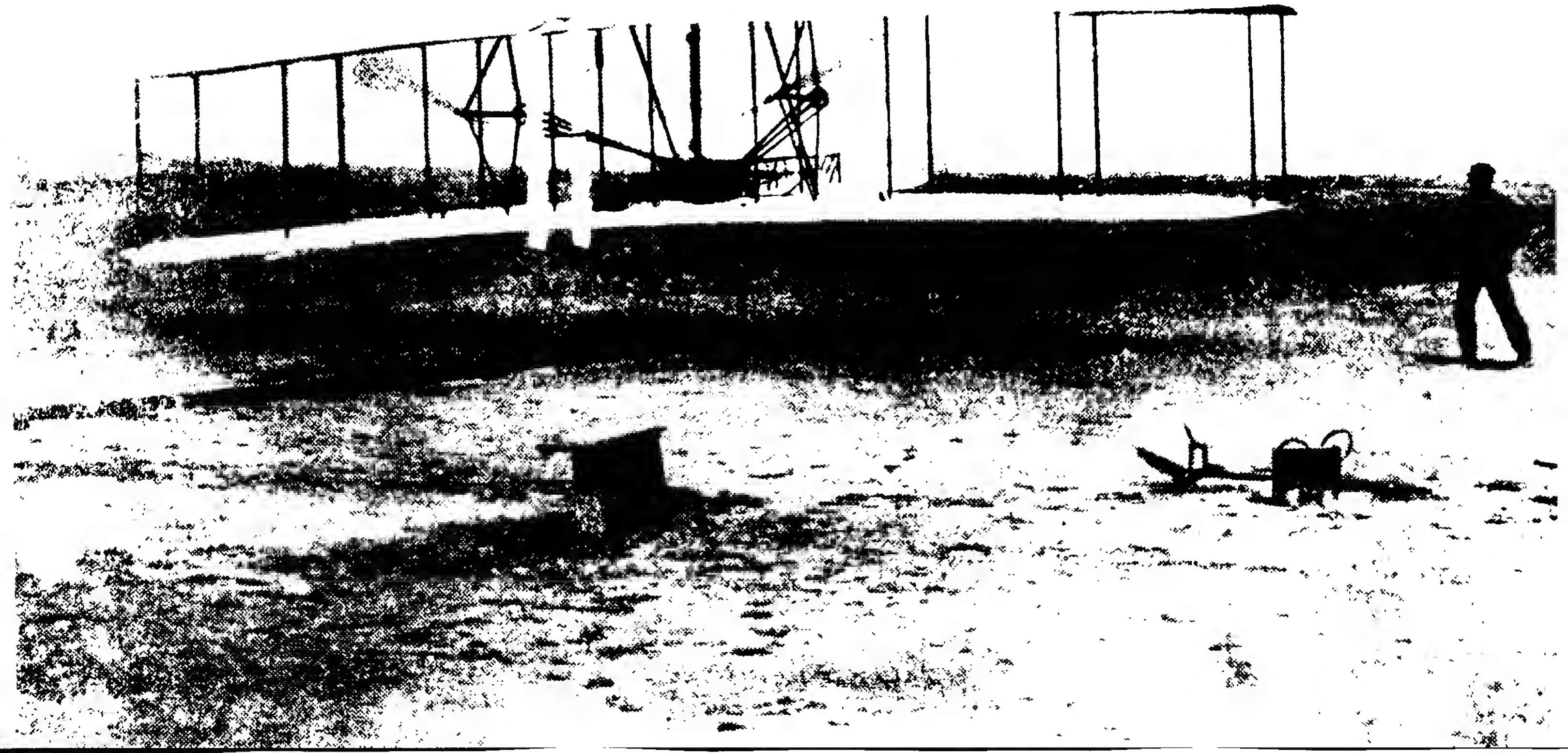
A CASE HISTORY IN ENGINEERING DESIGN

REPORT NO. 2-64



Designation of surface	4	5	6	7	8	9	10	11	12 ✓	13	15	16	17 ✓
Angle of incidence 0°	19½	16	13½	18	12¾	11	17½	15½	14¾	18½	19¾	19¾	20
2½°	11¾	9	7¾	7½	5½	4	6¾	6	5½	5½	12	11¼	10½
5°	7¾	5	4	3	2	1	2¾	1¾	1	5	8¼	7	6
7½°	4⅞	2½	2¼	½	-¼	-1½	1	-¼	-1¾	3½	4⅞	4	3
10°	2¾	1	¾	-1¾	-3	-3¼	0	-1⅞	-3½	3	3	2	1⅛
12½°	1⅞	-⅛	-¼	-4½	-4⅞	-5	-½	-2⅛	-4⅞	2	1¾	0	-¼
15°	0	-1⅛	-1⅛	-6	-5½	-5	-1⅛	-2½	-4⅞	1¼	0	-1½	-2
17½°	-¾	-1⅞	-1½	-6⅛	-4⅞	-4	-1⅞	-3	-3⅛	⅞	-1⅛	-2¾	-3
20°	-2	-2½	-2	-5	-3⅞	-3	-2¼	-2⅜	-2¼	-⅞	-3⅛	4	-4½
25°	-3⅛	-2⅞	-2⅛	-3¾	-2	-1⅞	-3	-1⅞	-1⅛	-1⅞	-5	5¾	-4⅞
30°	-3⅞	-3	-2	-2	-1⅛	-1¼	-2	-1⅛	-1	-2½	-5½	-4	-2⅞
45°	-1⅞	-1½	-1⅛	-1⅞	-1⅛	-1	-1⅔	-1	-⅞	-1½	-2¼	-1⅞	-1½

Tangentials.



FOREWORD

This case history is one of a series intended for use in teaching engineering design. It consists of material from two sources: The narrative parts are quoted by permission from "The Wright Brothers as Aeornautical Engineers", by M. P. Baker, SAE Quarterly Transactions, Volume 5, No. 1, pages 1 to 17, January 1951. The direct quotations of Orville Wright's own account are taken from a deposition he gave as a witness in a lawsuit in 1920. Most of this deposition, together with other interesting material, is contained in a small booklet, How We Invented the Airplane, by Orville Wright, with an Introduction and Commentary by Fred C. Kelly, published in 1953 by the David McKay Company, Inc., in New York. The help given by these two sources is gratefully acknowledged.

This series of case histories is part of the Educational Development Program in the Department of Engineering, University of California, Los Angeles. Funds for preparing these cases were made available from a Ford Foundation grant. Among the many people who support this work, special thanks are due to Dean L. M. K. Boelter, Prof. A. B. Rosenstein, Prof. T. T. Woodson, Miss M. Hatch, Mr. P. Searls, and the Reports Group in the UCLA Engineering Department, who take care of the all-important details of publication.

H. O. Fuchs
January 1964

No. 821,393.

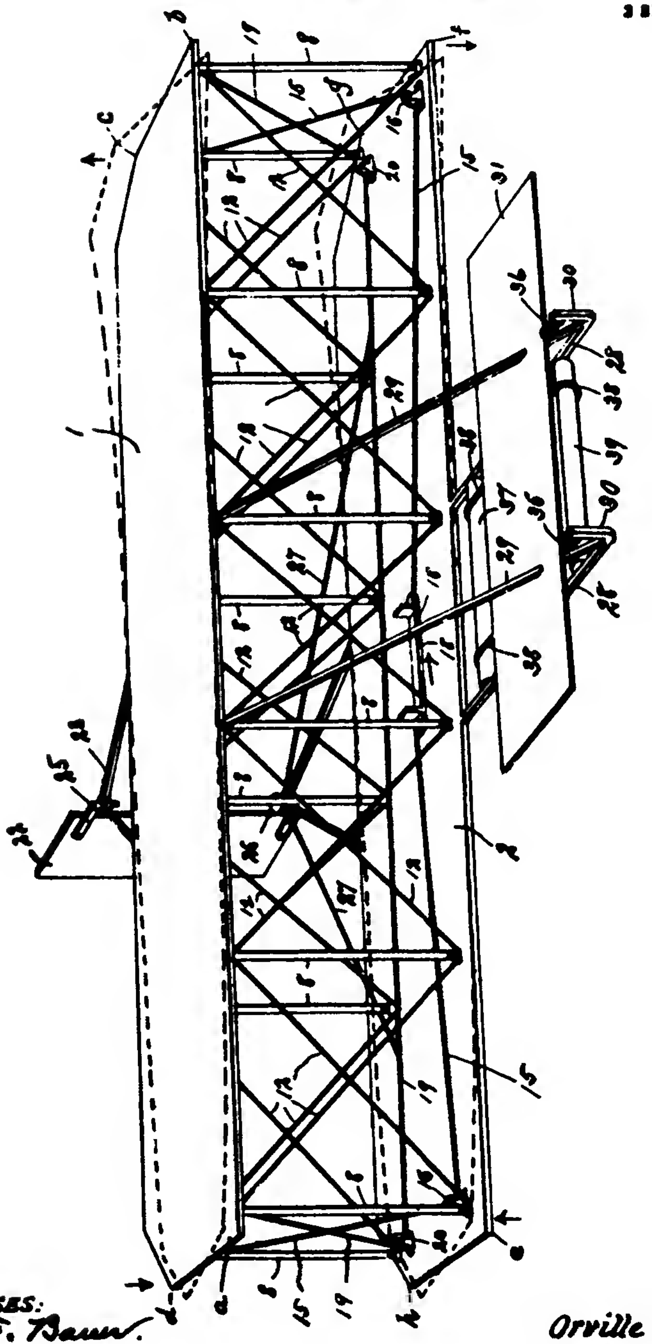
PATENTED MAY 22, 1906.

O. & W. WRIGHT.

FLYING MACHINE.

APPLICATION FILED MAR. 23, 1903.

3 SHEETS—SHEET 1.



WITNESSES:

William F. Bauer.

Irvine Miller.

INVENTORS.

Orville Wright

Wilbur Wright

BY H. A. Toulmin

ATTORNEY.

Wilbur Wright's active interest in aeronautics dated back to 1896. As his brother, Orville, related

> In 1896 we read in the daily papers, or in some of the magazines, of the experiments of Otto Lilienthal, who was making some gliding flights from the top of a small hill in Germany. His death a few months later while making a glide off a hill increased our interest in the subject, and we began looking for books pertaining to flight.

After studying all the literature that was handily available on the subject of aeronautics, the two of them drew some rather positive conclusions from what they had read:

1. A fixed-wing structure was far more practical than any scheme of flapping wings.
2. The customary method of obtaining longitudinal and lateral control merely by shifting the operator's weight on the craft was highly inadequate. They felt that such a system necessitated a degree of skill and dexterity that it was impossible to attain.
3. By proportioning a wing on the basis of known lift and drag characteristics of a chosen curved surface, and by providing a manual system for longitudinal and lateral control, one should be able to build an efficient glider in which considerable flight experience could be safely accumulated.

The problem of providing longitudinal control was no particular obstacle, there being the possibility of using a horizontal "rudder" behind the wing or, preferably, in front of the wing where there was less chance of its being damaged on landings. Also, much thought was given to the problem of lateral control.

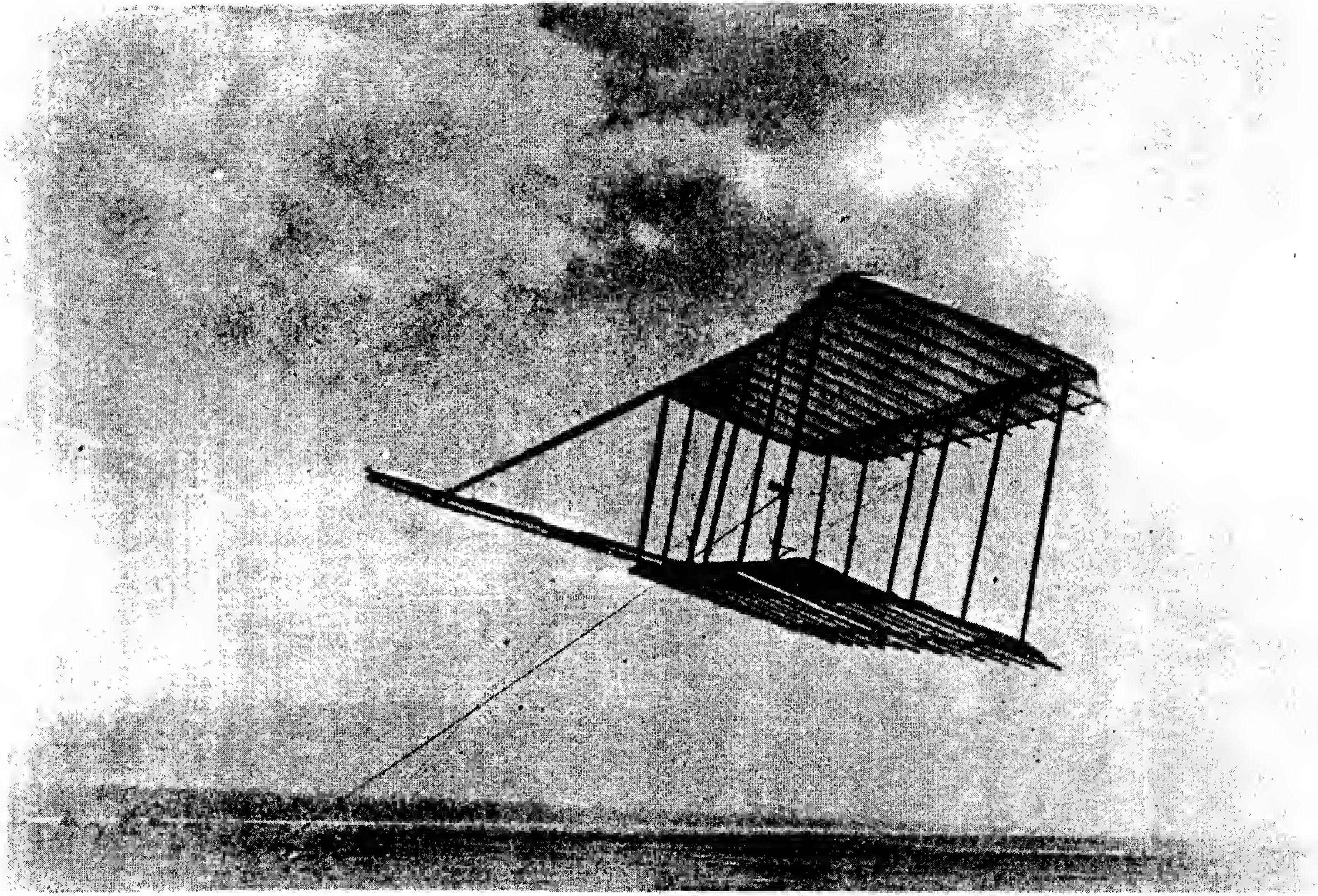
> The first method that occurred to us for maintaining the lateral equilibrium was that of pivoting the wings on the right and left sides on shafts carrying gears at the center of the machine, which, being in mesh, would cause one wing to turn upward in front when the other wing was turned downward. By this method we thought it would be possible to get a greater lift on one side than on the other, so that the shifting of weight would not be necessary for the

> maintenance of balance. However, we did not see any method of building this device sufficiently strong and at the same time light enough to enable us to use it.
>
> A short time afterward, one evening when I returned home with my sister and Miss Harriet Silliman, who was at that time a guest of my sister's in our home, Wilbur showed me a method of getting the same results as we had contemplated in our first idea without the structural defects of the original. He demonstrated the method by means of a small pasteboard box, which had the opposite ends removed. By holding the top forward corner and the rear lower corner of one end of the box between his thumb and forefinger and the rear upper corner and the lower forward corner of the other end of the box in the like manner, and by pressing the corners together, the upper and lower surface of the box were given a helicoidal (spiral) twist, presenting the top and bottom surfaces of the box at different angles on the right and left sides. From this it was apparent that the wings of a machine of the Chanute double-deck type, with the fore-and-aft trussing removed, could be warped in like manner, so that, in flying, the wings on the right and left sides could be warped so as to present their surfaces to the air at different angles of incidence and thus secure unequal lifts on the two sides.

1900 - The First Year's Work

With characteristic enthusiasm, the Wrights designed, built, and tested their first full-scale glider (Figure 1) in the summer of 1900. Lateral control was attained by warping the wing tips, presumably by an interconnecting wire across-ship, and somehow actuated by the feet. There was no means, whatever, provided for directional control.

> We felt that the model had demonstrated the efficiency of our system of control. After a little time we decided to experiment with a man-carrying machine embodying the principle of lateral control used in the kite model already flown. From the table of Lilienthal we calculated that a machine having an area of a little over 150 square feet would support a man when flown in a wind of sixteen miles an hour. We expected to fly the machine as a kite and in this way we thought we would be able to stay in the air for hours at a time, getting in this way a maximum of practice with a minimum of effort. In September of 1900 we went to Kitty Hawk, North Carolina, and there assembled the machine, most of the parts of which we had made at Dayton.



1900 GLIDER BEING FLOWN AS SIMPLE KITE
- CONTROLLABLE FROM GROUND

FIGURE 1

> From the United States Weather Bureau reports we had found that Kitty Hawk was one of the windiest places in the country, and that during the month of September it had an average wind in the neighborhood of 16 miles an hour.
>
> We attempted to fly the machine as a kite with a man on board a number of times, but were successful in keeping it up only when the wind was about twenty-five miles an hour. It failed to perform in lifting as had been calculated from the Lilienthal tables of air pressure.

Although their actual glider flight time totaled scarcely over two minutes for some 12 flights, the summer's experiments did permit them to draw some very valuable conclusions:

1. Their method of wing warp was quite satisfactory, and proper pitching control could be obtained by means of a movable horizontal "rudder".

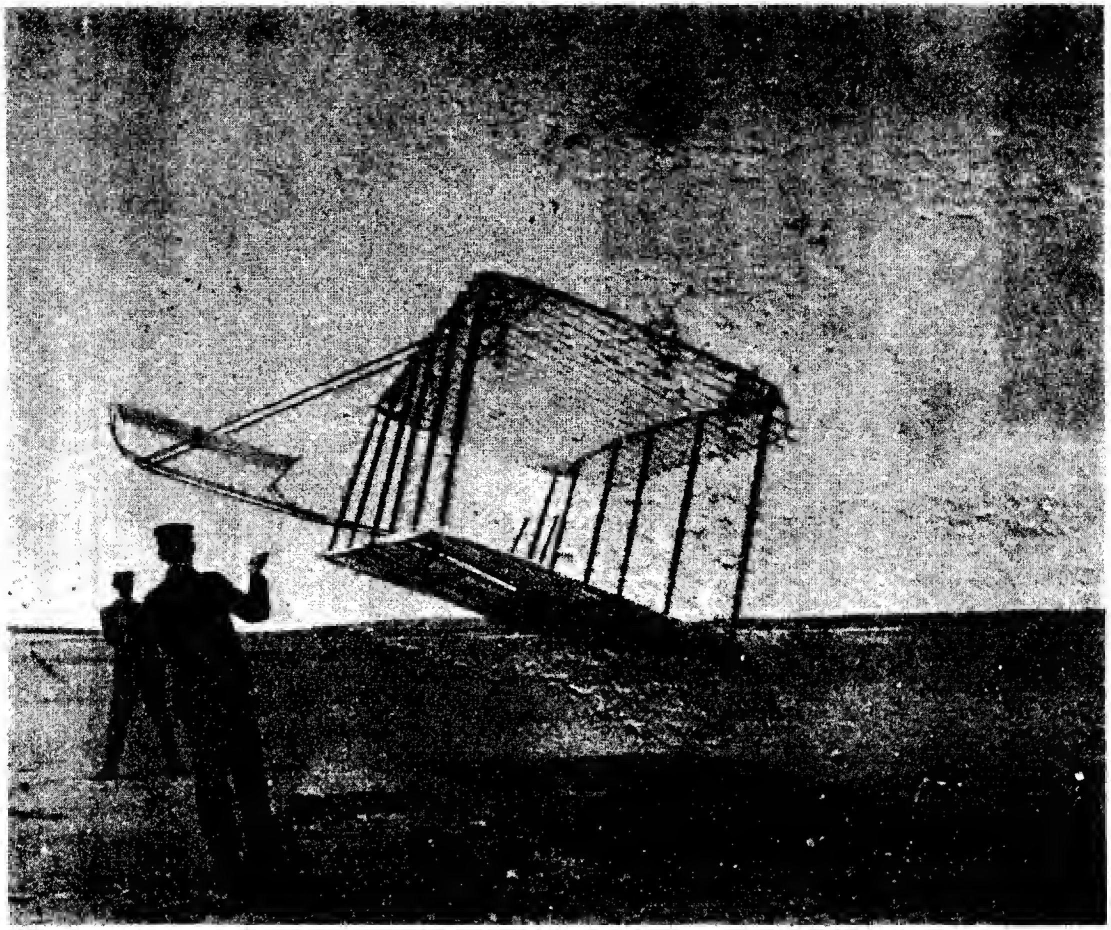
2. Their lift was less than anticipated, which they reasoned might be due to using too flat a camber, air leaks in the unfinished cloth wing covering, or possible error in Lilienthal's tables of lift characteristics.

3. Their drag measurements were much less than they had estimated. There seemed no explanation for this unless the Lilienthal tables were in error.

Further Experiments Through 1901

Encouraged by their first year's experiments, the Wrights designed and built a larger glider (Figure 2).

> We decided to increase the size of the machine of 1901, as well as to make the ribs and wings of a deeper curvature fore and aft. The 1901 machine was assembled at Kitty Hawk, or rather, near the Kill Devil Hill, in July 1901. The structure was very similar to that of the previous year. The method of imparting a helicoidal warp to the wings used in 1900 was used again in 1901: The area of the wings was increased from 165 square feet of the 1900 machine to 290 square feet, the wings having a spread of 22 feet, and a chord of seven feet. The depth of curvature of the wings was increased to one-twelfth of the chord, the deepest point being about 33 percent back.



1901 GLIDER BEING FLOWN AS KITE

FIGURE 2

> In the gliding flights the fore-and-aft stability or control of the machine did not seem to be as good as that of the previous year. This we finally suspected was due to the difference in the curvature of the wings of the two machines. We also found that where the machine of 1900 continued to increase in speed as we glided down certain slopes of the hill, the 1901 machine did not do so. This seemed to indicate that the machine of 1900 was able to glide on slopes of less angle than the machine of 1901, and was therefore dynamically more efficient. The lateral control of the new machine appeared very effective. As a result of these experiments we soon decided to reduce the curvature of the wings, which we did by a system of posts and wires about midway between the front and rear spars. These intermediate posts also served to prevent the ribs and wings from taking a deeper curvature due to the air pressure upon them. It had been found that the curvature of the wings was constantly changing during flight. The machine as thus modified was flown a number of times in gliding flights and as a kite with and without an operator on board. A number of measurements were made of the machine flown as a kite to determine the lift and the drift at various angles of incidence. The results obtained did not agree at all with the estimated values computed from Lilienthal and other accepted tables of air pressure.

Aside from the valuable flight experience gained with this machine, the summer's observations taught them the following:

1. Published lift characteristics for curved surfaces were definitely in error.
2. Overall efficiency depended upon L/D rather than lift alone.
3. The relative position of the upper and lower wings decreased the theoretical total lift of the individual surfaces; that is, they noticed biplane effect.
4. The customary method of expressing the air force acting on a wing in terms of a pressure normal to the chord line had led them into a misconception of the net lift and drag components. Although they did not express their understanding of this in these words, there seems little doubt that this was the primary motive in designing the test instruments that will be described later.

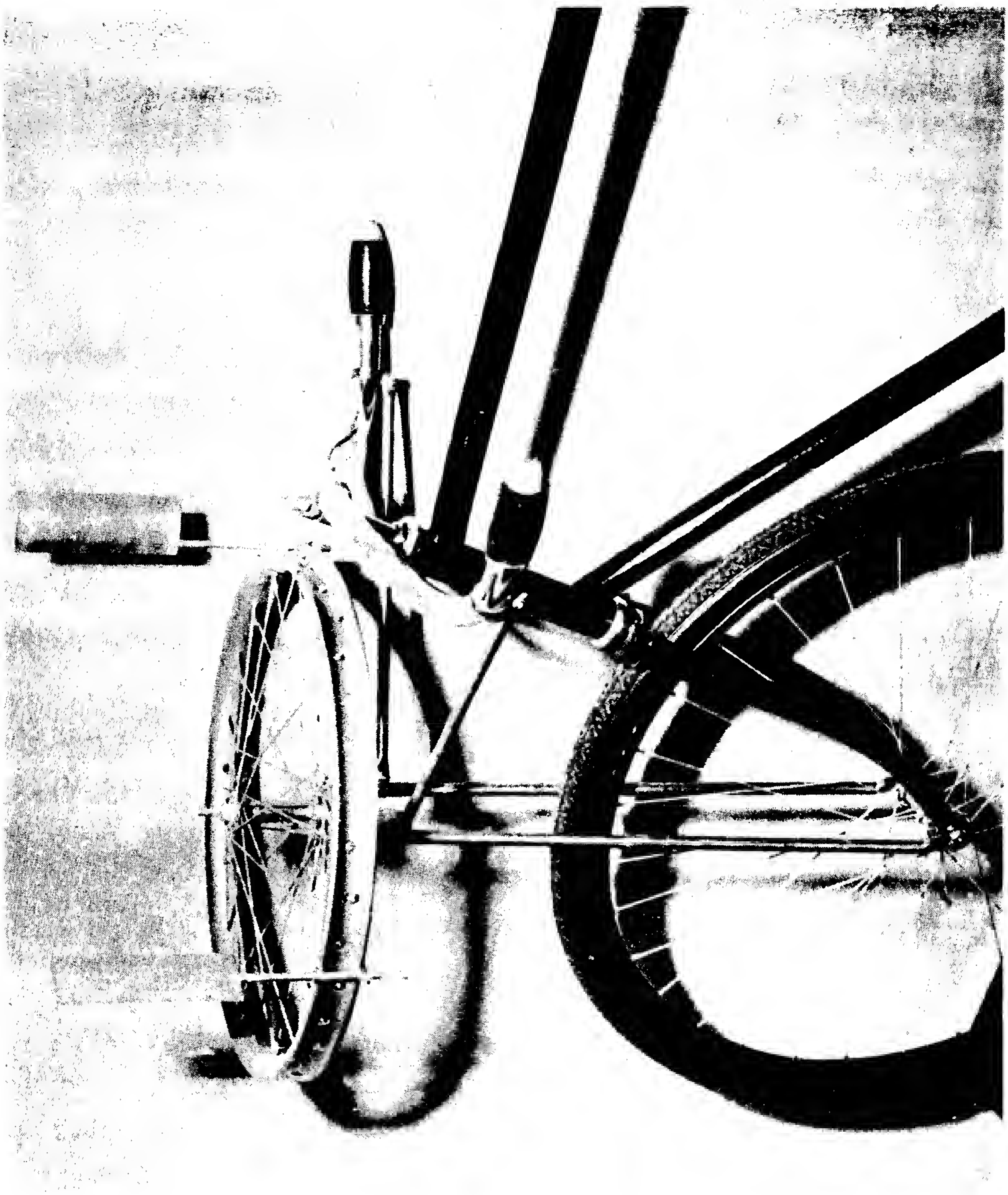
In a paper read on September 18, 1901, before the Western Society of Engineers, primarily a society of civil engineers, Wilbur Wright mentioned a series of experiments that they had begun for measuring the magnitude and direction of the forces acting on various types of curved surfaces. We know now that these experiments began upon their return from North Carolina and followed a rather interesting development pattern.

Test Instruments

The first attempt at measuring the characteristics of a surface in model size is shown in Figure 3. Here we see a bicycle wheel mounted horizontally on tubes extending forward from the handlebars of an ordinary bicycle (of their own manufacture). At one point on the wheel was mounted a flat plate. Some 120 degrees removed from this point was mounted the model surface. The test surface was adjusted in angle of attack until its lift would just balance the flat-plate resistance riding normal to the wind when the bicycle was pedaled forward.

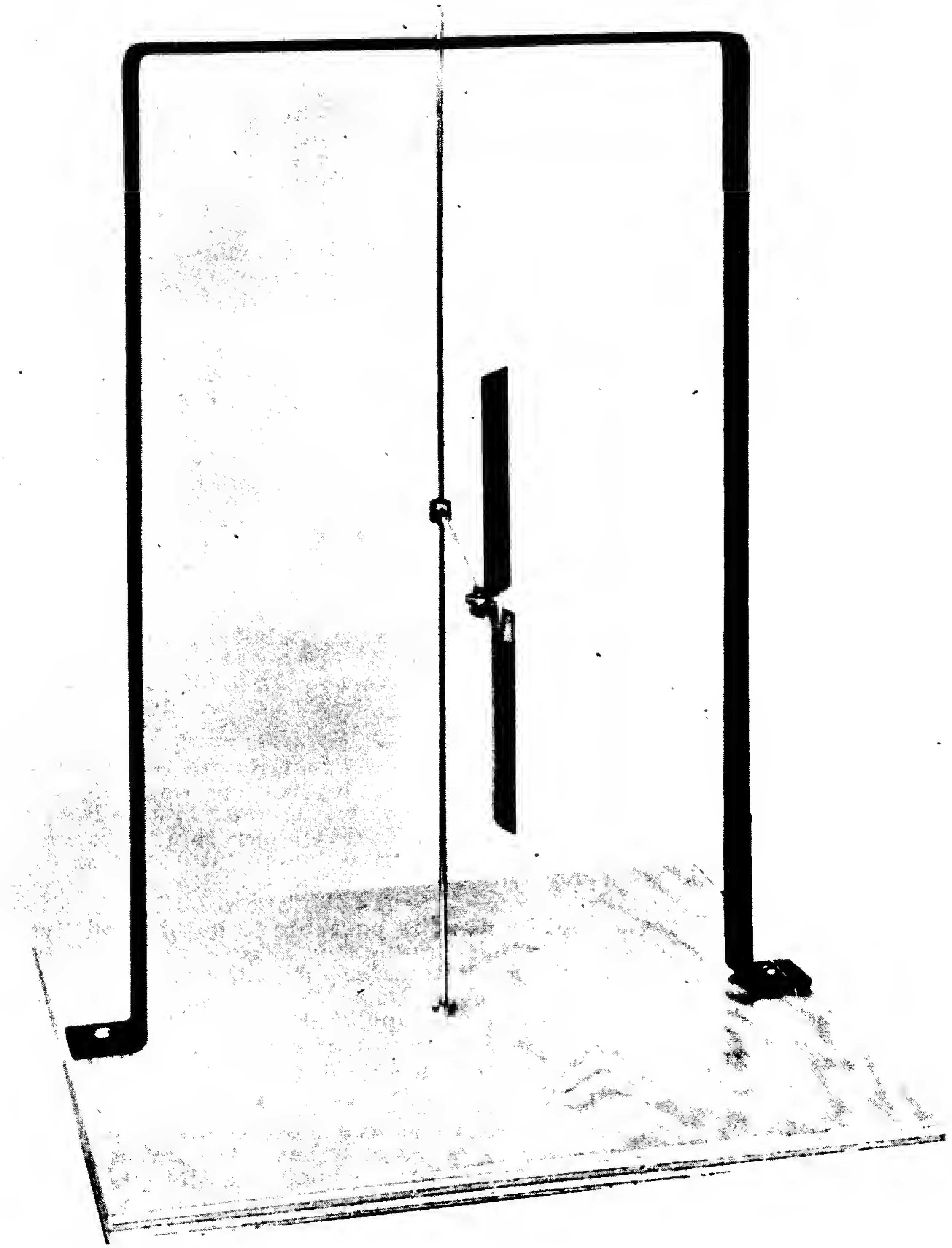
In a letter to Octave Chanute on October 6, 1901, Wilbur told about using this device and how they were able to check the ratio of the lift of a surface at any angle of attack versus its flat-plate resistance. Also, he noted that the Smeaton formula for flat-plate resistance, $P = 0.005\ AV^2$, as used by the United States Weather Bureau, was evidently in error, and suggested that a constant of 0.0033 would be nearer the truth.

In this same letter, Wilbur stated that the bicycle test was very poor for measuring surfaces at small angles and went on to describe their next device, shown in Figure 4. Note that two surfaces are attached to a trailing arm in wind-vane fashion and each can be adjusted until their opposing lifts balance. Later correspondence brings out the fact that this was their first attempt at using a wind tunnel and that it was actually made by knocking the ends out of a box used in those days for shipping laundry starch. An air blast was supplied from the opposite end by a screw fan turning at 4000 rpm. No doubt this was driven from their machine-shop lineshafting, which incidentally, was driven in turn by a 2-hp gasoline engine of their own design.



WRIGHTS' FIRST DEVICE FOR COMPARING LIFT CHARACTERISTICS OF MODEL SURFACE AGAINST FLAT-PLATE RESISTANCE

FIGURE 3



BALANCING VANE USED IN STARCH BOX TUNNEL

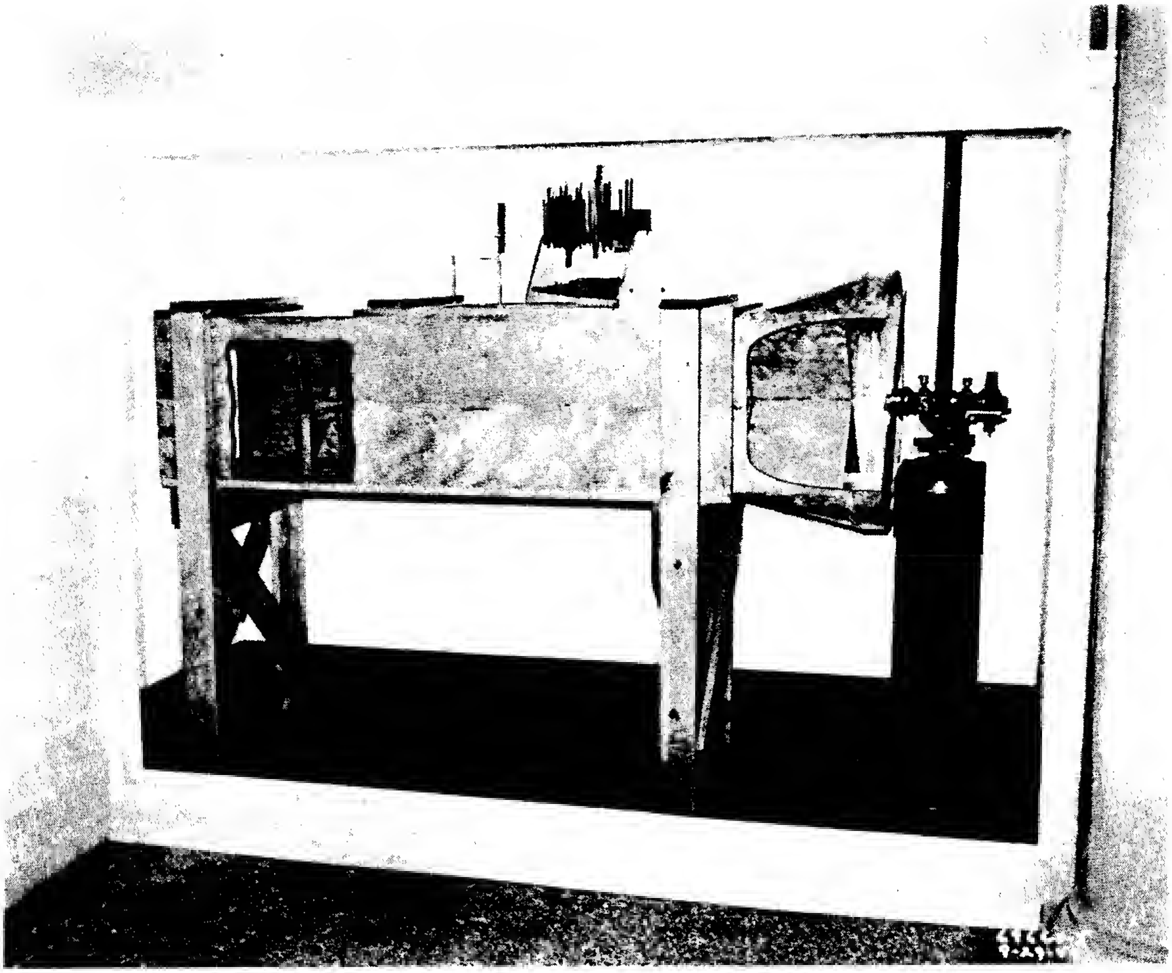
FIGURE 4

With this device they experimented with various aspect ratios and curvatures. One particular observation that was recorded was the balancing of a 1x3 inch curved surface at 4-3/4 degrees against a flat-plane of the same area at 9-1/2 degrees, whereas their reference tables indicated they should have balanced at angles of 4-3/4 and 24 degrees, respectively. The correspondence files include a letter to Chanute, wherein Wilbur pointed out a number of these discrepancies. Chanute very promptly answered back that they were comparing results taken from moving wind measurements against measurements that had been made in still air. It was rather amusing to note Wilbur's reply that this should make no difference, although he did temper his brusqueness by explaining how easy it would have been for the particular investigator to have made mistakes by the method he was using.

Compared with the first device, this method was far more accurate and served to make many more comparisons in a short time; however, it still did not provide the means of making direct measurements and was soon abandoned.

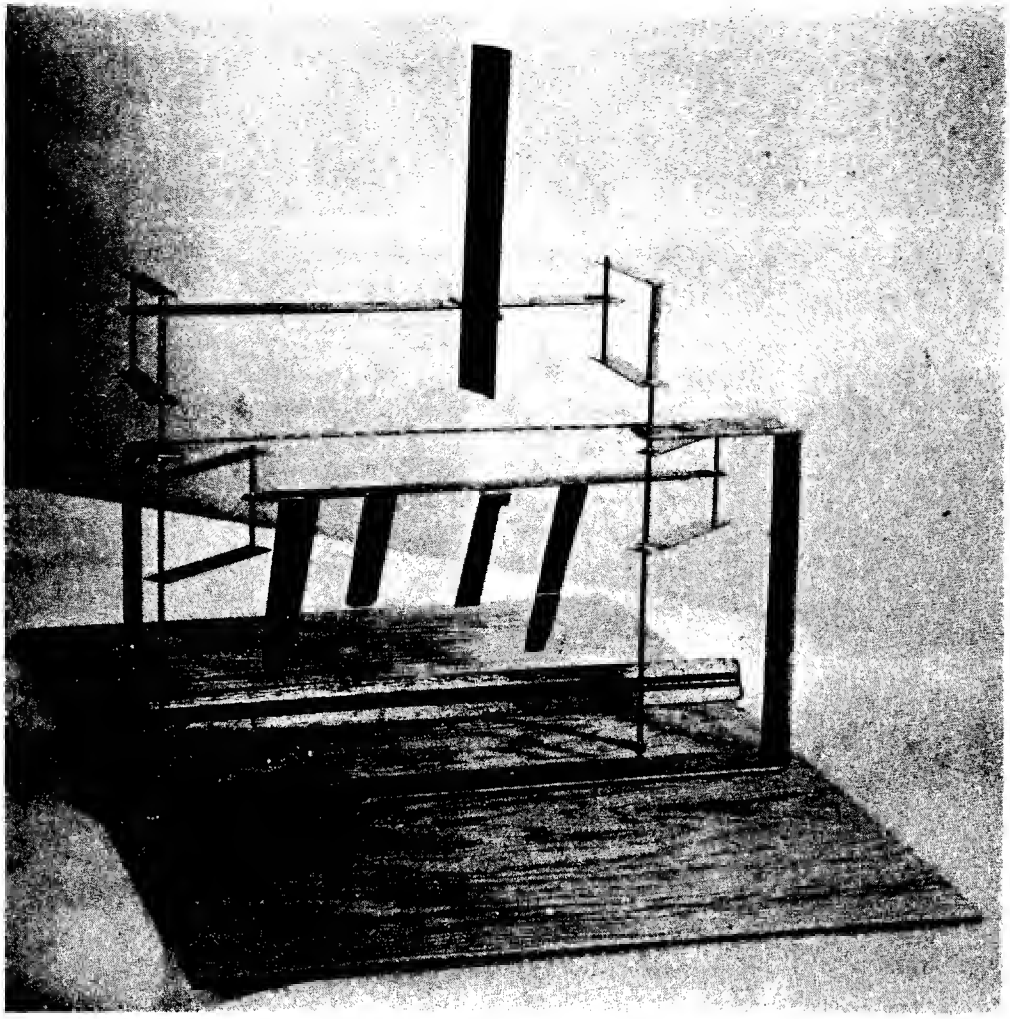
The third and final type of measuring instrument was evidently built and put into operation sometime between October 16 and November 14, 1901. During that time they built a tunnel like that shown in Figure 5. This is as near to an exact replica as it is possible to build from the available information. The lift instrument (see Figure 6), which was placed at the downwind end, is an exact copy of the original, which is now on display at the Franklin Institute in Philadelphia.

Perhaps the most unique feature of this instrument is the way in which the lift of a model surface is made to balance the flat-plate resistance of four small fingers on the lower bar. The shackle arms, which support the upper crossbeam, are snug on the vertical pins and are adjusted so that they trail straight with the wind stream. Since the resistance or lower beam must ride at some angle to the side in order to balance the lift of the test surface, it is obvious that the sine of the angle



WRIGHT BROTHERS WIND TUNNEL

FIGURE 5



WIND-TUNNEL INSTRUMENT FOR MEASURING LIFT
- AIR MOVES IN SAME DIRECTION AS
OBSERVER IS LOOKING

FIGURE 6

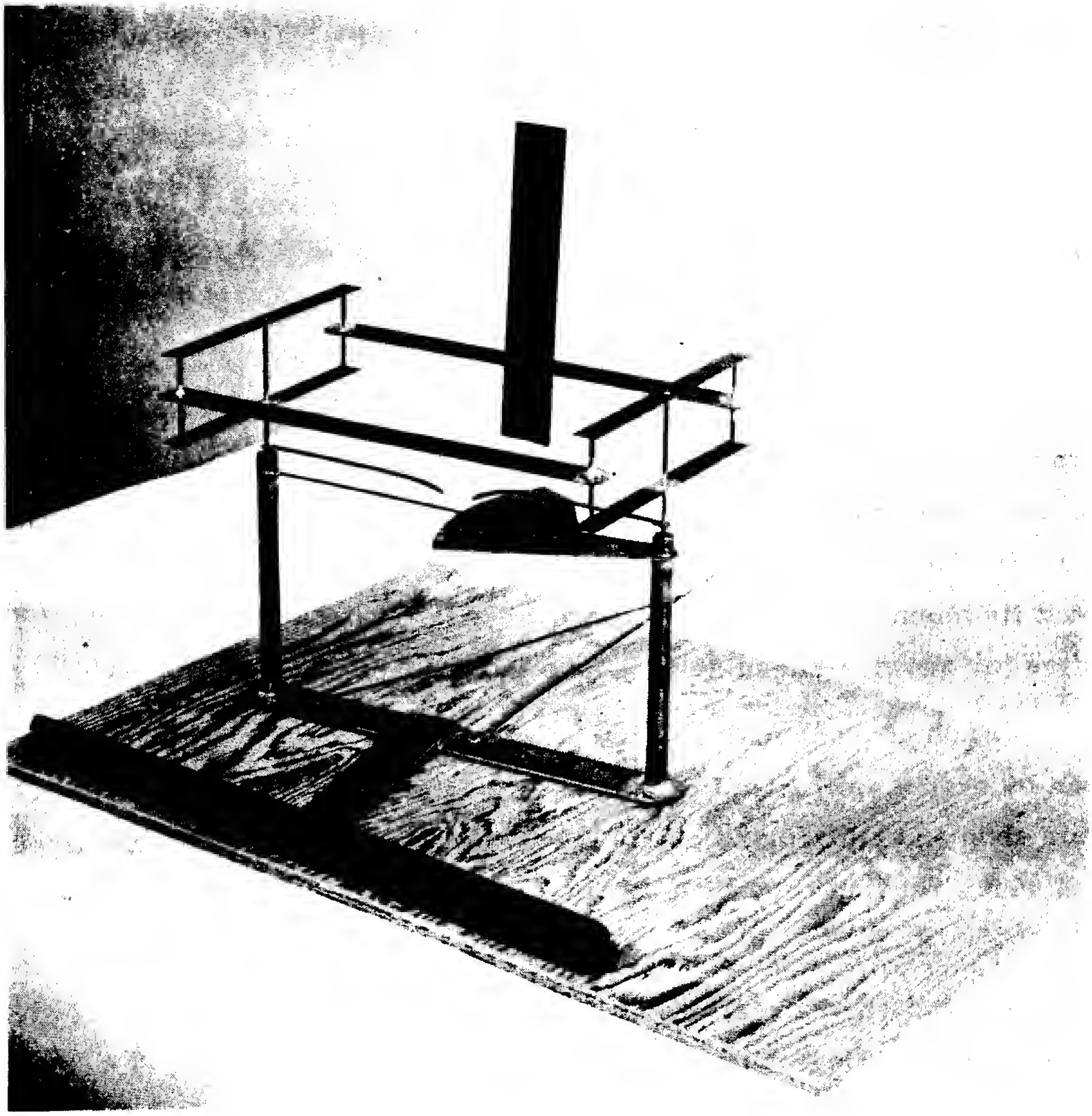
observed on the scale is the true lift coefficient. The angle of attack was recorded by a separate protractor. A two-bladed 24-inch-diameter propeller fan mounted on the shaft of their shop bend grinder driven at 3000 rpm provided a wind velocity of about 27 mph. The precautions taken to insure a straight flow included the quadrant shield, a grid frame, and small areas of wire mesh at strategic points on the grid.

The files indicate that the Wrights had a method of altering this instrument to measure drag, but as it was not too satisfactory they soon developed a separate instrument for that purpose. Figure 7 shows that the drag instrument was just as ingenious as the other, but with the difference that here they measured D/L rather than drag alone. Note that the lift acts in the direction of the shackle arms, and therefore, the tangent of the angle indicated by the dial pointer is really the prevailing D/L ratio. The angle of attack could be adjusted readily by turning the whole assembly about its mounting screw. The product of the lift coefficient and the D/L ratios for any model and setting gave the drag coefficient.

Each of these instruments is surprisingly sensitive when acted upon by even a very light breeze. By closing all doors and windows of their shop and allowing no one to move about in the room, they obtained data which require very little fairing to plot as smooth curves.

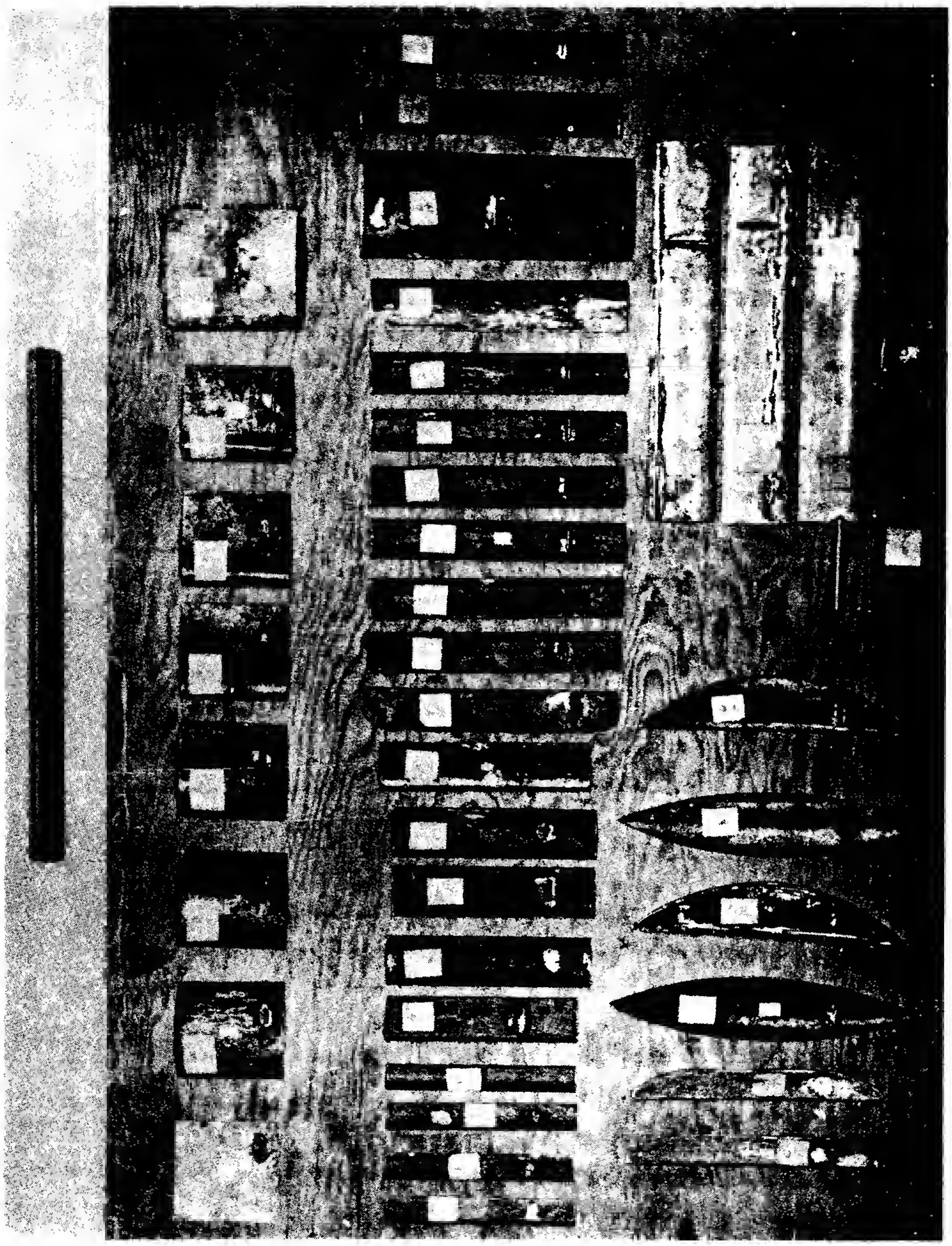
Figure 8 is a photograph of their remaining test models, and Figures 9 and 10 are reproductions of two pages from their records giving some of their typical data.

At the beginning of this test work, the Wrights believed that lift was proportional to the angle of attack, and we can well imagine their surprise at suddenly observing one day that the lift for one particular surface was the same at 30 degrees as it was at 50 degrees. Here again, we note their ingenuity in mounting two of this type of surface on vane arms at an 80 degree spread and checking to see if the surfaces balance in the tunnel at 30 and 50 degrees. This device is shown in Figure 11.



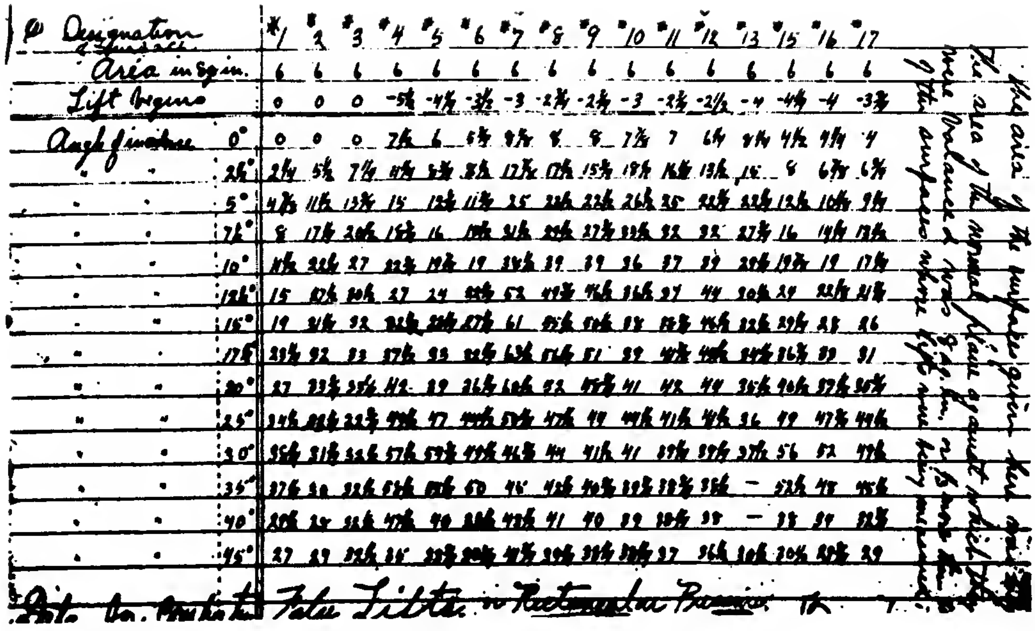
WIND-TUNNEL DRAG INSTRUMENT - AIR FLOWS FROM RIGHT PARALLEL TO LONG BEAMS

FIGURE 7



COLLECTION OF ORIGINAL TEST SPECIMENS

FIGURE 8



Designation

Area in sq in.

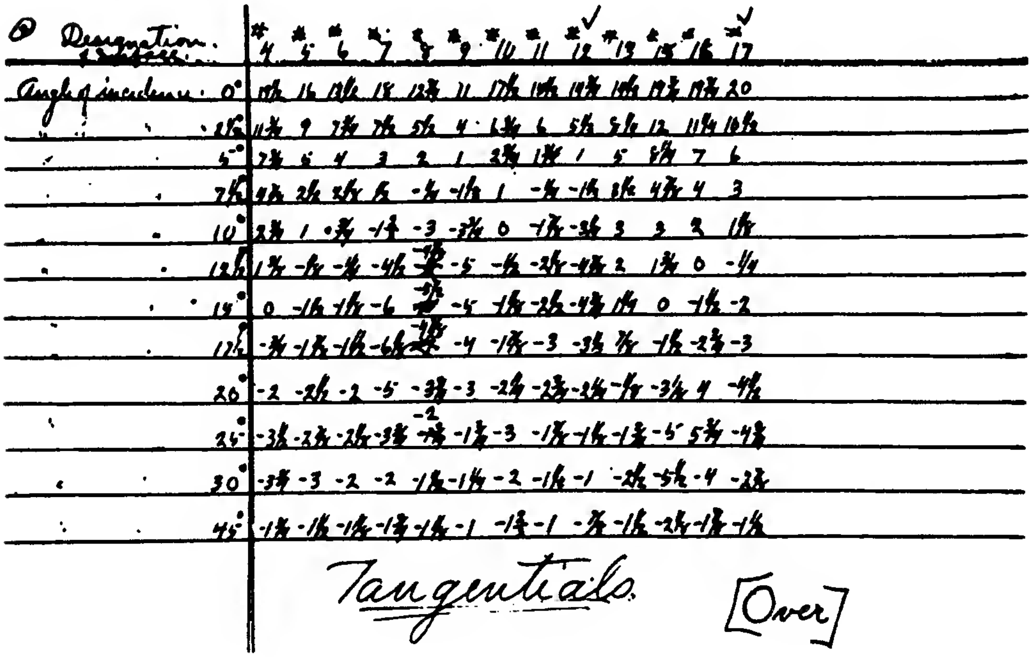
Lift begins

Angle of incidence

Lift in Rectangular Boxes

REPRODUCTION OF ONE PAGE OF LIFT RECORDINGS AS WRITTEN DOWN BY WILBUR WRIGHT

FIGURE 9



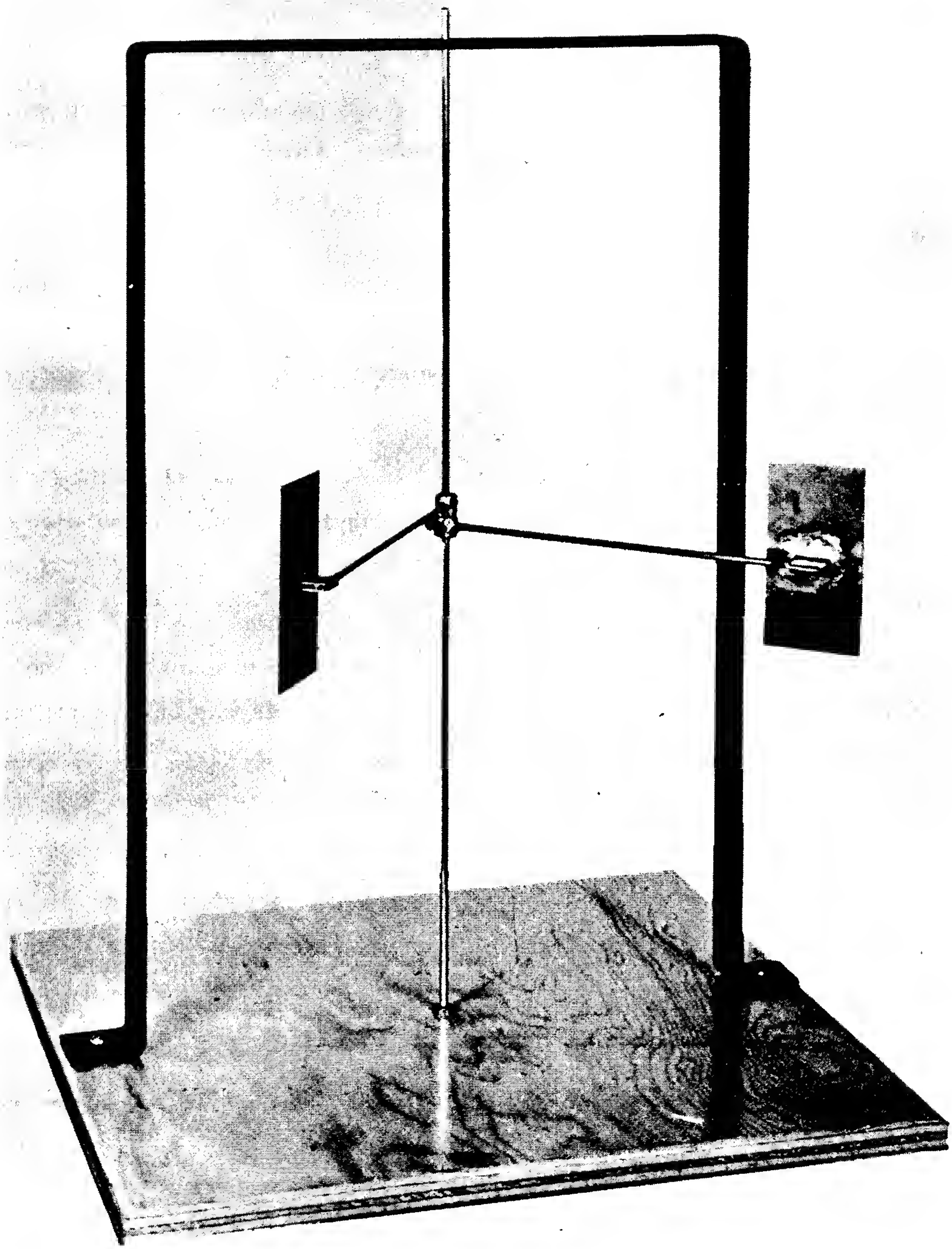
Designation

Angle of incidence

Tangentials. [Over]

DRAG READINGS

FIGURE 10



RECHECK VANE

FIGURE 11

At the completion of their test program, the Wright brothers not only had an imposing collection of measured data but were also able to draw the following conclusions:

1. Increasing aspect ratio does not increase maximum lift but does lower the attack angle at which maximum lift occurs.

2. Curvature gives greater lift to a surface and a steadier rate of increase.

3. The camber ratio of a curved surface has a more marked effect on drag.

4. By having the maximum-camber point forward, lift is increased at the smaller angles.

They observed the inefficiency of biplane effect. Also, they observed the effects of the taper and cutouts in the wing plan form. They noted the stall point, although they didn't define it as such.

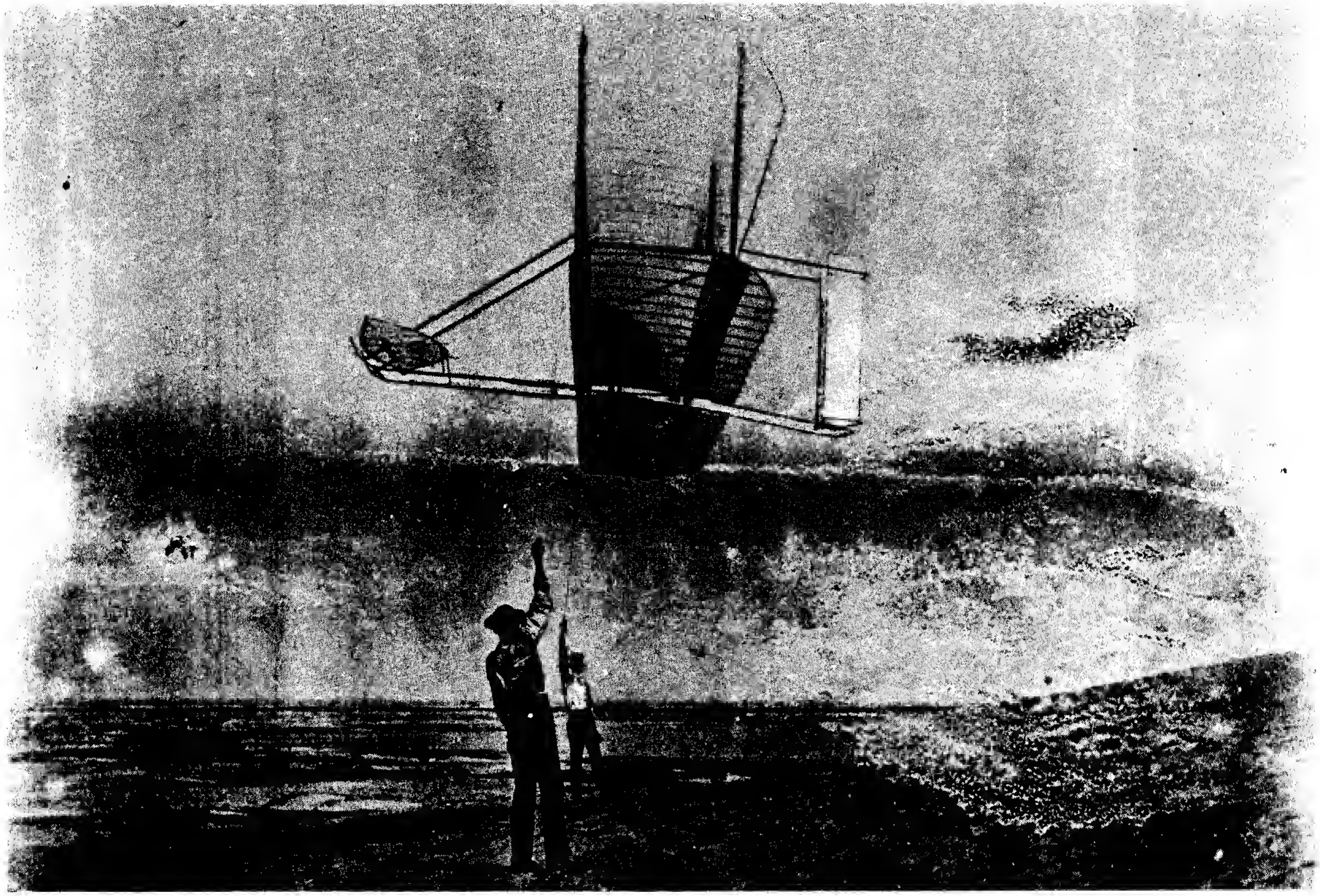
The accuracy of these conclusions is truly amazing when we consider the size of their models and the short time they had to accumulate the information. We must not overlook the fact that this was quite contradictory to and beyond the work of all other investigators who were "better" equipped. The importance of this phase of their work is best expressed in Wilbur's own words of 1908:

> As soon as our condition is such that constant attention to our business is not required, we expect to prepare for publication the results of our laboratory experiments, which alone made an early solution of the flying problem possible.

Unfortunately, this ambition was never fulfilled. This phase of their work was completed in February of 1902.

Advance Glider Work in 1902

Fortified with considerable flight experience and many design data in which they had complete confidence, the Wrights returned to North Carolina in the late summer of 1902 and constructed their third glider. (See Figure 12.)



1902 GLIDER BEING FLOWN AS KITE

FIGURE 12

From the photograph it is apparent that this machine incorporated all the refinements found necessary in the earlier models and, in addition, was fitted with a pair of fixed vertical fins for directional stability.

The gross weight without operator was 116.5 lb. The elevator was controlled by a window sash chord over pulleys (by the hand), and wing warp was operated by wires running from a cradle in which the operator's hips rested.

The lift/drag ratio of the new machine was soon established in a measured glide as 8.77. The ratio of their best previous machine had been slightly less than six. The new elevator was very efficient, requiring only three degrees either side to maintain complete pitch control. By flying the upper wing alone as a kite and by measuring all of their glides carefully, they substantiated the results of their wind-tunnel experiments.

In addition to the valuable flight experience they accumulated on this machine in almost 1000 glides in two months, they learned how to overcome a rather vicious tendency to stall in the turns by replacing the fixed vertical fins with a single movable rudder controlled by interconnection with the wing warping. They later revealed this idea in their patent 821,393 granted May 22, 1906.

Powered Flight

The season's work gave them utmost confidence in their ability to add an engine and continue their work in powered flight. Orville Wright explained the next steps as follows:

> Immediately after our return from Kitty Hawk in 1902 we wrote to a number of the best-known automobile manufacturers in an endeavor to secure a motor for the new machine. Not receiving favorable answers from any of these, we proceeded to design a motor of our own, from which we hoped to secure about eight horsepower. When the motor was tested it gave more power than we had anticipated. It developed a little over twelve horsepower and weighed about 160 pounds, without magneto, water, or oil.
>
> We next proceeded with the construction of the parts to be used in this first power machine, and while we were doing this we began an investigation of screw propellers. At first we hoped

> to be able to procure a theory of the reactions on a screw propeller from works on marine engineering, but we soon found, after examining the few books we were able to secure in the Dayton Public Library pertaining to marine engineering, that water screw propellers at that time were not based upon theory but almost entirely upon empirical data. We had thought that we could adopt the theory from the marine engineers, and then by using our tables of air pressures, instead of the tables of water pressures used in their calculations, that we could estimate in advance the performance of the propellers we would use. When we found we could not do this, we began the study of the screw propeller from an entirely theoretical standpoint, since we saw that with the small capital we possessed we would not be able to develop an efficient air propeller on the "cut and try" plan. As a result of this study we developed a theory from which we designed the propellers which we used in this 1903 power machine.
>
> These propellers had an efficiency of over 66 percent, an efficiency, I believe, rarely exceeded by the marine engineers, and never approached by any of the aeronautical investigators up to that time.

The year 1903 must have been an exceedingly busy one for the Wright brothers. In March they applied for their first patent; on June 18, Wilbur wrote a letter stating that their engine developed 15.6 hp at the "brake", thus indicating its early completion; and we know that by fall they were in North Carolina making final assembly of the airplane. In addition to all of this, they still found considerable time that fall to practice flying in the previous year's glider.

> We went to Kitty Hawk the latter part of September 1903, and after a few days spent in establishing camp and in erecting a building in which to assemble and house our new machine, we began the work of assembling.
>
> The first attempt to fly this machine was made on the 14th day of December, but through a mistake in handling it at the start the machine was broken slightly, so that repairs had to be made before another attempt could be undertaken. Five men from the Kill Devil Life Saving Station were present when this test was made. The next trial was made on the 17th of December, in a wind blowing 20 miles, and four more flights were made. The first of these covered a distance of about 100 feet, measured from the end of the track and had a duration of about twelve seconds. The second and third

> flights covered about 175 feet, and the fourth flight 852 feet. This last flight had a duration of 59 seconds.
>
> The machine was launched from a monorail track... This track was laid in a slight depression, which a few days before had been covered by water. We chose this spot because the action of the water had leveled it so nearly flat that little preparation of the ground was necessary in order to lay the track. The starting end of the track lay a few inches below the end from which the machine lifted into the air.
>
> A small two-wheeled truck ran on the track. Across the truck extended a beam, upon the two opposite ends of which the skids of the machine rested. A bicycle hub was attached at the forward end of the skids, beneath the elevator. This supported the forward end of the machine and guided the machine on a rail.
>
> The machine was launched entirely through the power of the motor and the thrust of the propellers.
>
> In the last flight the rate of travel over the ground was approximately ten miles per hour against a wind of approximately 20 miles per hour, making the real speed of the machine through the air about 30 miles an hour.
>
> The first of these flights...was the first time in the history of the world that a machine carrying a man and driven by a motor had lifted itself from the ground in free flight.
>
> Witnesses of this flight, besides my brother and myself, were John T. Daniels, W. S. Dough, A. D. Etheridge, from the Kill Devil Life Saving Station; W. C. Brinkley, of Manteo; and Johnny Moore, a boy from Nags Head, North Carolina.

From a study of the design details of this machine (now on public display at the Smithsonian Institute in Washington) it is easy to note the general characteristics that are similar to the 1902 glider. The front elevators were doubled and actuated by a unique arrangement of controls such that the surfaces not only deflected in the desired direction but also changed in camber, that is positive camber for "nose-up" and negative camber for "nose-down". The wing-warp system was retained but was refined by better routing of the control wires and the use of bellcranks. The vertical rudders were made multiple surfaces and interconnected with the wing warp as before. Note that, as always, the warp wires served not only as controls but also as structure rigging wires.

For the first time, we see cloth covering used on both the top and bottom surfaces of each wing. The wings were intentionally rigged to a ten inch droop measured at the tips. This was the equivalent of a negative 2-1/2 degree dihedral.

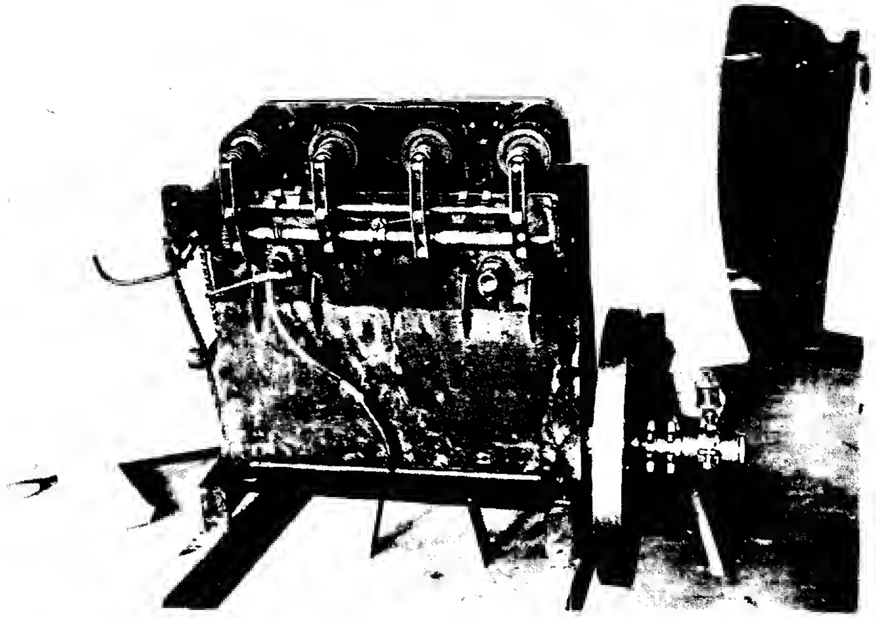
The ship was taken off (without assist) from a 60-foot monorail. Most of the craft's weight rested on a jettisonable truck, which rolled on two small tandem wheels having flanges that fit over the edges of the monorail. A smaller wheel made from a bicycle wheel hub was permanently attached to the front skid. The ship was restrained by a cable until released by the operator. A small string from the release cable pulled the fuel valve to wide-open position and then broke readily as the ship moved forward.

The Engine

Throughout all of their writings, the Wrights seemed to depreciate the design of their early engines, and yet, as we look over their work now, we see innumerable instances of outstanding ingenuity.

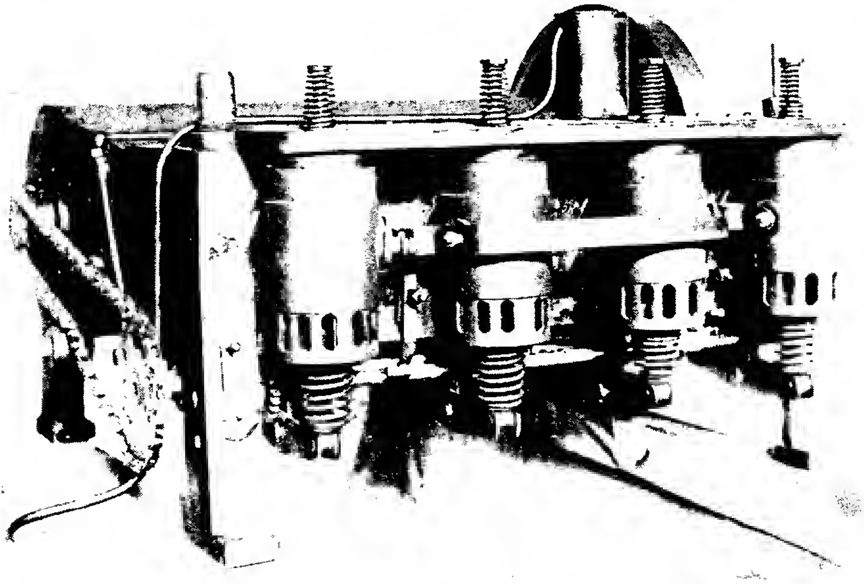
The "Kitty Hawk" had a horizontal 4-cycle engine of 4-inch bore (chosen for high displacement) and 4-inch stroke (chosen in the interest of light weight). (See Figures 13 and 14.) The cylinders were individual cast-iron units fitted into a single-piece cast-aluminum crankcase that extended far enough to form a water jacket around the cylinder barrels. A camshaft driven from the crankshaft by a chain operated the exhaust valves and the individual breaker arms for cylinder firing. The intake valves were spring closed and opened by natural aspiration.

The ignition for running was supplied by a low-tension horseshoe generator with induced electromagnetic field, driven by a contact wheel against the flywheel. A starter box, not carried in the airplane, containing four dry-cell batteries and a homemade inductance coil made by wrapping bell wire around a core of cut lengths of broom wire furnished a hot spark for starting only. The spark timing was retarded for starting by a cam movement to advance the normal position of the camshaft sprocket, thus changing the exhaust-valve timing at the same time. Most of the "old-timers"



BOTTOM VIEW OF 1903 ENGINE TAKEN JUST BEFORE ITS SHIPMENT TO ENGLAND IN 1928
(note oil pump has been added, although this was not used at time of original Kitty Hawk flights)

FIGURE 13



SIDE VIEW OF 1903 ENGINE SHOWING VALVES - FLYWHEEL IS AT REAR END

FIGURE 14

recall that the Wrights' early engines started easily. Cooling water for the engine was supplied by thermosiphon flow from a long, narrow radiator mounted on one of the center-section struts.

The instrumentation provided was solely for the purpose of obtaining flight records. A Veeder counter on the engine recorded total revolutions from take-off until landing. A Richards anemometer, with interconnected stop watch actuated by a cord from the fuel valve, measured the air traversed in meters.

Further Development

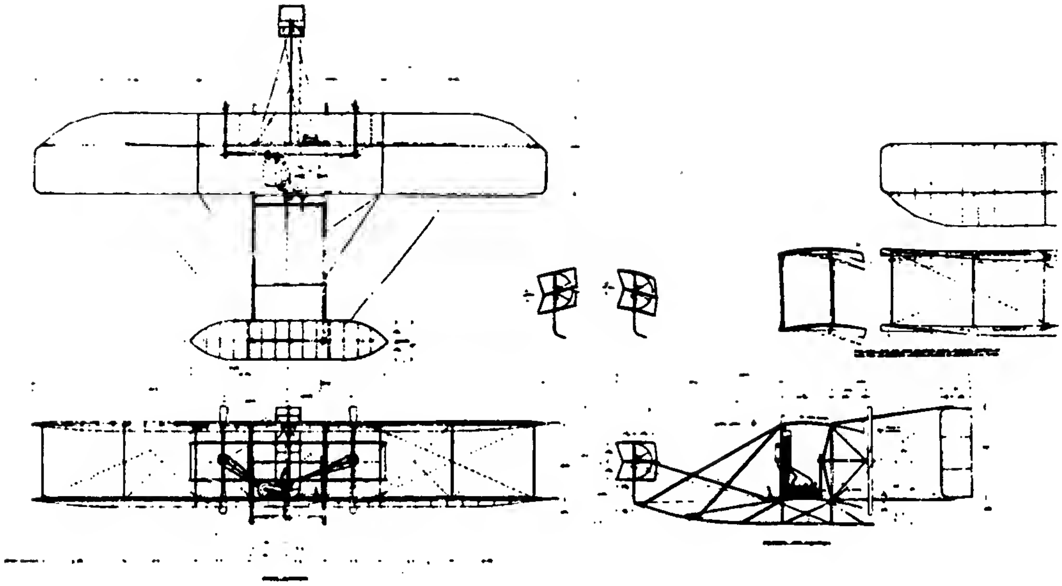
A second airplane was built in 1904 and tested at Dayton throughout the summers of 1904 and 1905. This airplane is of particular interest in that it was really the development step between the 1903 prototype and the "practical flyer", as Wilbur put it. (See Figure 15.)

The years of 1906 and 1907 were devoted to intense developing and testing of an airplane that would be of practical value to the United States Army. In 1908 the final form of this machine was successfully demonstrated by Orville to carry two occupants over a closed 125-mile course at a speed of 42 mph. (See Figure 16.)

In this machine, a new vertical engine was used to provide space for the extra passenger. The hip yoke for the wing warp was replaced by a hand lever, both occupants now sitting upright. The rudder control was not interconnected.

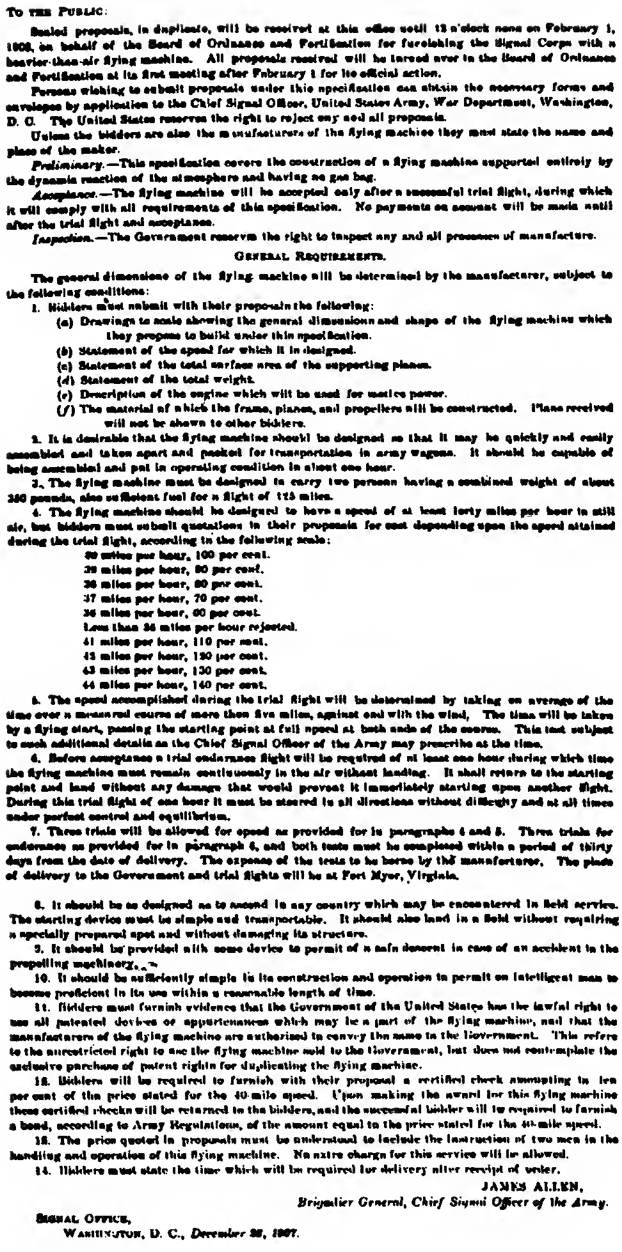
In a paper of this length it is impossible to cover all the many incidents of historical interest, the lack, it is hoped, being compensated for by a more complete recording of the steps taken to develop one of our greatest inventions from first conception to a "reduction to practice" salable machine.

The Wright brothers made mistakes in their nine years of work, to be sure, and they can easily be accused of doing some things the "hard way", but a serious student of their work cannot avoid developing respect for the engineering ability of these two men.



RECENT THREE-VIEW DRAWING OF 1905 AIRPLANE

FIGURE 15



TO THE PUBLIC:

Sealed proposals, in duplicate, will be received at this office until 12 o'clock noon on February 1, 1908, on behalf of the Board of Ordnance and Fortification for furnishing the Signal Corps with a heavier-than-air flying machine. All proposals received will be turned over to the Board of Ordnance and Fortification at its first meeting after February 1 for its official action.

Persons wishing to submit proposals under this specification can obtain the necessary forms and envelopes by application to the Chief Signal Officer, United States Army, War Department, Washington, D. C. The United States reserves the right to reject any and all proposals.

Unless the bidders are also the manufacturers of the flying machine they must state the name and place of the maker.

Preliminary.—This specification covers the construction of a flying machine supported entirely by the dynamic reaction of the atmosphere and having no gas bag.

Acceptance.—The flying machine will be accepted only after a successful trial flight, during which it will comply with all requirements of this specification. No payments on account will be made until after the trial flight and acceptance.

Inspection.—The Government reserves the right to inspect any and all processes of manufacture.

GENERAL REQUIREMENTS.

The general dimensions of the flying machine will be determined by the manufacturer, subject to the following conditions:

1. Bidders must submit with their proposals the following:
    (*a*) Drawings to scale showing the general dimensions and shape of the flying machine which they propose to build under this specification.
    (*b*) Statement of the speed for which it is designed.
    (*c*) Statement of the total surface area of the supporting planes.
    (*d*) Statement of the total weight.
    (*e*) Description of the engine which will be used for motive power.
    (*f*) The material of which the frame, planes, and propellers will be constructed. Plans received will not be shown to other bidders.

2. It is desirable that the flying machine should be designed so that it may be quickly and easily assembled and taken apart and packed for transportation in army wagons. It should be capable of being assembled and put in operating condition in about one hour.

3. The flying machine must be designed to carry two persons having a combined weight of about 350 pounds, also sufficient fuel for a flight of 125 miles.

4. The flying machine should be designed to have a speed of at least forty miles per hour in still air, but bidders must submit quotations in their proposals for cost depending upon the speed attained during the trial flight, according to the following scale:

40 miles per hour, 100 per cent.
39 miles per hour, 90 per cent.
38 miles per hour, 80 per cent.
37 miles per hour, 70 per cent.
36 miles per hour, 60 per cent.
Less than 36 miles per hour rejected.
41 miles per hour, 110 per cent.
42 miles per hour, 120 per cent.
43 miles per hour, 130 per cent.
44 miles per hour, 140 per cent.

5. The speed accomplished during the trial flight will be determined by taking an average of the time over a measured course of more than five miles, against and with the wind. The time will be taken by a flying start, passing the starting point at full speed at both ends of the course. This test subject to such additional details as the Chief Signal Officer of the Army may prescribe at the time.

6. Before acceptance a trial endurance flight will be required of at least one hour during which time the flying machine must remain continuously in the air without landing. It shall return to the starting point and land without any damage that would prevent it immediately starting upon another flight. During this trial flight of one hour it must be steered in all directions without difficulty and at all times under perfect control and equilibrium.

7. Three trials will be allowed for speed as provided for in paragraphs 4 and 5. Three trials for endurance as provided for in paragraph 6, and both tests must be completed within a period of thirty days from the date of delivery. The expense of the tests to be borne by the manufacturer. The place of delivery to the Government and trial flights will be at Fort Myer, Virginia.

8. It should be so designed as to ascend in any country which may be encountered in field service. The starting device must be simple and transportable. It should also land in a field without requiring a specially prepared spot and without damaging its structure.

9. It should be provided with some device to permit of a safe descent in case of an accident to the propelling machinery.

10. It should be sufficiently simple in its construction and operation to permit an intelligent man to become proficient in its use within a reasonable length of time.

11. Bidders must furnish evidence that the Government of the United States has the lawful right to use all patented devices or appurtenances which may be a part of the flying machine, and that the manufacturers of the flying machine are authorized to convey the same to the Government. This refers to the unrestricted right to use the flying machine sold to the Government, but does not contemplate the exclusive purchase of patent rights for duplicating the flying machine.

12. Bidders will be required to furnish with their proposal a certified check amounting to ten per cent of the price stated for the 40-mile speed. Upon making the award for this flying machine these certified checks will be returned to the bidders, and the successful bidder will be required to furnish a bond, according to Army Regulations, of the amount equal to the price stated for the 40-mile speed.

13. The price quoted in proposals must be understood to include the instruction of two men in the handling and operation of this flying machine. No extra charge for this service will be allowed.

14. Bidders must state the time which will be required for delivery after receipt of order.

JAMES ALLEN,
Brigadier General, Chief Signal Officer of the Army.

SIGNAL OFFICE,
WASHINGTON, D. C., *December 23, 1907.*

REPRODUCTION OF SPECIFICATION SHEET FOR FIRST U. S. ARMY AIRPLANE

FIGURE 16

If there is a keynote to be noticed, it would best be expressed as balance. In their thinking they balanced the advantages against the disadvantages, in their measuring they balanced the unknown against the known, and in their flight instruction to others they stressed the development of a sense of balance. Perhaps it was their skill as expert bicycle riders in boyhood that influenced their way of thinking in maturity.

THE WALL STREET JOURNAL, MONDAY. JUNE 2, 1969

Themes *and* Variations

* * *

Flying Machine

WASHINGTON — The Pentagon takes its lumps these days for alleged mismanagement of big weapons contracts. Accounts of the C5A, Mark II Avionics and other items, too complex for most of us to understand, bring continual cries about extra billions spent unnecessarily.

Perhaps the trouble all began with U.S. Army Signal Corps Specification No. 486.

The notice to contractors was most precise about what was needed: "Advertisement and specification for a heavier-than-air flying machine," it read. And the request for contractors' bids brooked no technological backsliding, but firmly set forth the scientific principle involved: "This specification covers the construction of a flying machine supported entirely by the dynamic reaction of the atmosphere and having no gas bag."

Likewise, performance standards were rigid. The machine had to carry 350 pounds of crewmen, have fuel for 125 miles and make a good 40 miles an hour "in still air." Brigadier General James Allen, who signed No. 486 back in 1907, also had a "desirable" option in mind: The machine would be viewed more favorably if it could "be quickly and easily assembled and taken apart and packed for transportation in Army wagons."

Army tacticians were obviously keeping up with the times. In event of war, they wanted a flying machine that horses could pull quickly from one battlefield to another. The machine also had to be ready to "ascend in any country which may be encountered in field service."

Forty-one would-be builders sought the order, and three made firm proposals. Though its bid was the highest received, a small business concern known as "Wilbur and Orville Wright, trading as Wright Brothers," of 1127 West Third Street, Dayton, Ohio, was the winner. Some basic research at Kitty Hawk years before gave them the edge, especially after one competitor, a Mr. J. F. Scott of Chicago, concluded that he couldn't produce a flying machine for $1,000 as promised. The Wrights agreed to "manufacture for and deliver to the United States of America one (1) heavier-than-air flying machine."

The price was $25,000, with bonuses or penalties for top speeds above or below the required 40 mph a possibility. This early incentive clause worked; the Wrights' flying machine Model A (Serial 1) averaged 42.583 miles an hour without a gas bag and earned them an extra $5,000, according to archives at Wright-Patterson Air Force Base.

Thus history saw its first aircraft contract price overrun, though no Congressional subcommittee bothered to investigate.

Other precedents were soon established, launching today's military-industrial complex. The Wrights, no slouches, slyly improved their machine and soon sent Model B aloft under a new contract. Not long after, they cornered another big war department payoff for seven versions of Model C—two of which were promptly dispatched to the Philippines, setting another example.

Speed zoomed to 54 mph and the "design change" race was on. Other companies began to understand the game and clamored for contracts, on grounds their machines would fly higher, or cram into horse carts more quickly, or whatever. Eventually . . . the F111 and the ABM.

Congress saw what was coming, it seems. The Wrights' first contract stipulated that "No Member of or Delegate to Congress . . . is or shall be admitted to any share or part of this contract, or to any benefit which may arise therefrom." But a footnote wisely exempted interests in incorporated companies from this restriction. (A recent survey found 61 House members owning shares in corporations that profit from the military trade.)

And there is at least one other constant in this fast-changing world. The contract for the Wright Brothers' flying machine closes with these words:

"Executed in quintuplicate."

—ROBERT KEATLEY